Department of the Navy
Office of Naval Research
Contract N6onr - 24435
Project NR062-124

FINAL REPORT

Prepared by
Taras Kiceniuk
Research Engineer

Hydrodynamics Laboratory
CALIFORNIA INSTITUTE OF TECHNOLOGY
Pasadena, California

Report No. E-35.5 October 1959

Department of the Navy
Office of Naval Research
Contract N6onr-24435
Project NR062-124

FINAL REPORT

Prepared by

Taras Kiceniuk
Research Engineer

Hydrodynamics Laboratory
California Institute of Technology
Pasadena, California

Report No. E-35.5 October 1959

A. WORK STATUS AT BEGINNING OF CONTRACT

This contract was initiated in October 1950 to continue the basic research programs then in progress at this laboratory in several important areas in hydrodynamics. Studies under way at that time consisted of the following:

1. Cavitation

The mechanics of the growth and collapse of individual cavitation bubbles was being investigated with particular emphasis on the effects of the compressibility of the liquid and the accompanying energy dissipation in the shock and sound waves.

Experiments were being conducted to determine the nature of initial rupture of the liquid and of the effect of air content upon cavitation inception. Two different approaches were being used to evaluate this dependence. The first of these was based on the degree of superheat required to initiate boiling in carefully prepared samples of water (in a glass tube) at atmospheric pressure. The second employed a specially fabricated glass venturi tube through which the water was made to flow at high velocity (1)*.

2. Cavitation Noise

Correlation was established between visual observations of the extent of vapor cavitation on models in the High Speed Water Tunnel and acoustic pressure in the 20 to 100 kc range. Various velocities and model sizes had been used and the program was being extended to a study of the effect of model roughness on the degree of cavitation.

3. Water Entry

Free flight studies of torpedoes during water entry had been performed in the Controlled-Atmosphere Launching Tank, and accurate trajectory data had been obtained. The high launching velocities which are possible in this facility suggested that missile drag measurement could be performed at Reynolds Numbers greater than those available in the High Speed Water Tunnel. The launching tank was also shown to be well suited for investigating the pitch sensitivity of models because of the accuracy attainable both in the launching conditions and in the data analysis.

---

* Numbers in parenthesis refer to publication list on last page.

4. Dynamics of Underwater Bodies

A working dynamic balance had been completed and in use at this time for the purpose of studying the forces and moments acting on submerged bodies in nonsteady flow. This balance, used in conjunction with the High Speed Water Tunnel, measured certain dynamic coefficients by oscillating the model through small angles about the yaw axis.

B. INVESTIGATIONS ACTIVELY STUDIED UNDER THIS CONTRACT

During the period of active execution of this contract, investigations were continued or intensified in those areas where scientific interest remained high, yet the program remained flexible enough to pursue new challenging problems as they arose.

1. Cavitation

The effect of model size, material, and surface contour and roughness on incipient cavitation was exhaustively studied in the High Speed Water Tunnel both by visual inspection and by acoustic methods (2). Techniques for measuring the dissolved air content of the water permitted exploration of the effect of this parameter on cavitation inception. Continued uncertainty about the effect of model size on incipient cavitation number (2, 3), and the effect of using different facilities to obtain data in the same or similar models prompted a joint study with the Ordnance Research Laboratory, Pennsylvania State College. Through this joint effort (4), which made available the services of the 48-in. Garfield Thomas Water Tunnel, model size could be increased by a factor of three over those normally used in the High Speed Water Tunnel.

Visual observations of small cavitation bubbles upstream of the usually observed band of incipient cavitation suggested that failure to account for the presence of the boundary layer might be the cause of discrepancies between experimental observations and existing theory. Techniques and instruments were developed which shed new light on the growth of microscopic cavitation bubbles within the boundary layer and which revealed for the first time the existence of tension in ordinary water flowing around a body with incipient cavitation (5, 6).

In addition to the study of incipient cavitation near streamlined bodies, considerable research was done into the formation of cavities in the vortex cores behind bluff or sharp-edged bodies (6). The incipient cavitation number was found to be a function of model size and of water velocity. Estimates of the incipient cavitation number based on the vapor pressure of the water and on the minimum pressure coefficient for the flow under noncavitating conditions were found to be low compared to the observed values. This is in contrast to the case of streamlined bodies, where predictions made in this manner are high, and therefore conservative for most applications where cavitation is to be avoided.

2. Water Entry

Investigations of water entry problems sponsored by this contract were concentrated mainly on the effect of environmental conditions and model parameters in determining the range of valid dynamic modeling. Also, an experimental program was undertaken for studying in detail the collapse of the entry cavity behind simple geometrical bodies. High-speed photographs of the cavity were to be taken simultaneously with pressure measurements within the cavity. Only preliminary experiments were performed in this area.

3. Dynamics of Underwater Bodies

Investigations into the dynamics of underwater bodies resulted in the design and fabrication of two successful dynamic balances (Figs. 1, 2) for use with the High Speed Water Tunnel, and in the development of the theories and data-reduction techniques upon which their use depends. These two balances are known as the Angular Dynamic Balance (7) and the Translational Dynamic Balance.

Using both balances on a particular body permits the determination of eight of the dynamic coefficients (or stability derivatives, as they are commonly called). These coefficients are:

N_r' coefficient of rotary moment derivative

$N_{\dot{r}}'$ virtual moment of inertia coefficient (angular acceleration)

N_v' coefficient of static moment derivative

$N_{\dot{v}}'$ virtual moment of inertia coefficient (lateral acceleration)

Y_r' coefficient of rotary force derivative

$Y_{\dot{r}}'$ virtual inertia coefficient (angular acceleration)

Y_v' coefficient of static force derivative

$Y_{\dot{v}}'$ virtual inertia coefficient (lateral acceleration)

where the abbreviations are in accord with the recommendations of Technical and Research Bulletin No. 1-5, SNAME, "Nomenclature for Treating the Motion of a Submerged Body through a Fluid".

Table 1

Coefficients Determined by the Angular Balance

$N_{\dot{r}}'$	$Y_{\dot{r}}'$
$N_r' - N_{\dot{v}}'U$	$Y_r' - Y_{\dot{v}}'U$
N_v'	Y_v'

Table 2

Coefficients Determined by the Translational Balance

$Y_{\dot{v}}'$	$N_{\dot{v}}'$
Y_v'	N_v'

Using either balance alone does not permit unique determination of the important coefficients of rotary force and moment derivative. This must be achieved by combining the results from both balances.

Each of the dynamic balances operates without supplementary instrumentation to yield the coefficients in the left-hand column in Tables 1 and 2 and with accessory internal strain-gauge-type balances to give those in the right-hand column. Considering first the balances without the associated internal balance systems, the principle of operation is as follows:

A small oscillating sinusoidal motion is imparted to a driving platform by means of a specially generated cam. The cam in turn is connected to an electric motor rotating at some selected, accurately controlled speed. A system of springs of known stiffness connects this driving platform to the driven platform, which carries the model assembly. By measuring the displacements of each of these mechanical components at preselected times during each cycle, the steady-state amplitude ratio and phase angle of the mechanical system is determined. From these are found the equivalent spring, mass, and damping force of the mechanical-hydrodynamic system. The quantities are then related to the hydrodynamic coefficient through the linearized Taylor series expansion for the forces and moments acting on a submerged body which has been slightly disturbed from its steady-state condition.

The measurement of the displacement and phase angle of the mechanical components is accomplished by the use of an electronic flash lamp which is pulsed at a precisely known time in the cycle. The angular dynamic balance uses optical levers to determine the required angular displacements, and the translational balance uses a cathetometer which views a pair of lines scribed on small cards carried by the driving and driven platforms. In both cases a Fourier analysis of the driver and driven motions can be made, and the relative amplitudes and phase angles of the fundamental motion determined.

Since the motion of the driven platform is itself sinusoidal, it can also be regarded simply as an oscillator driving the instrumented model. With this device it is possible to measure forces on the angular balance and moments on the translational balance. An alternative method would require the use of alternate model support points on a series of runs. The output signal from the internal force or moment balance is compared to one from a controllable a-c tachometer generator mounted on the cam drive shaft. The a-c generator housing is trunnion-mounted to permit phase control of its output e.m.f. The instantaneous side force or moment reaction can, in this way, be determined. A computation procedure similar to the one used for the data from the main balance assembly converts these reactions into the desired hydrodynamic coefficients.

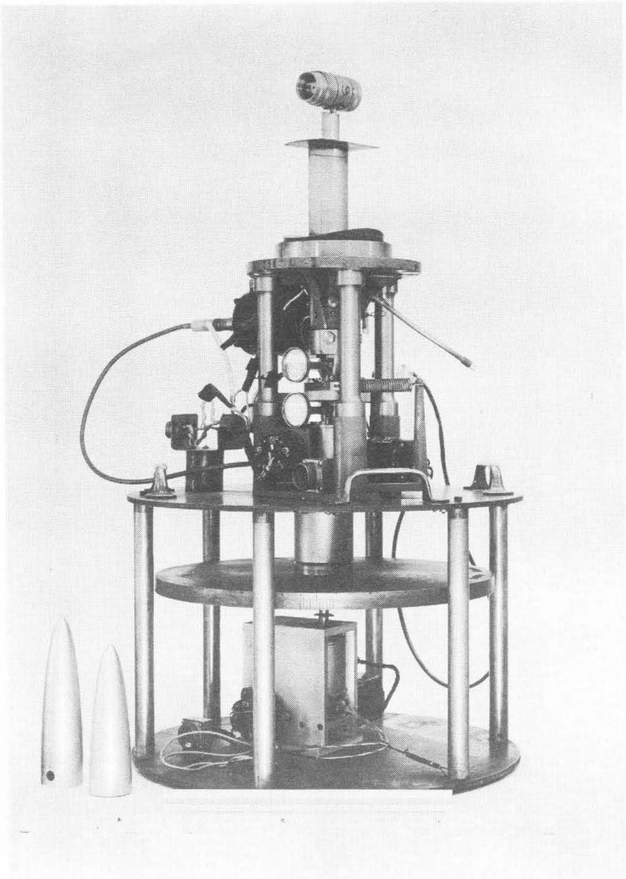

Fig. 1. Angular Dynamic Balance and Ellipsoidal Model

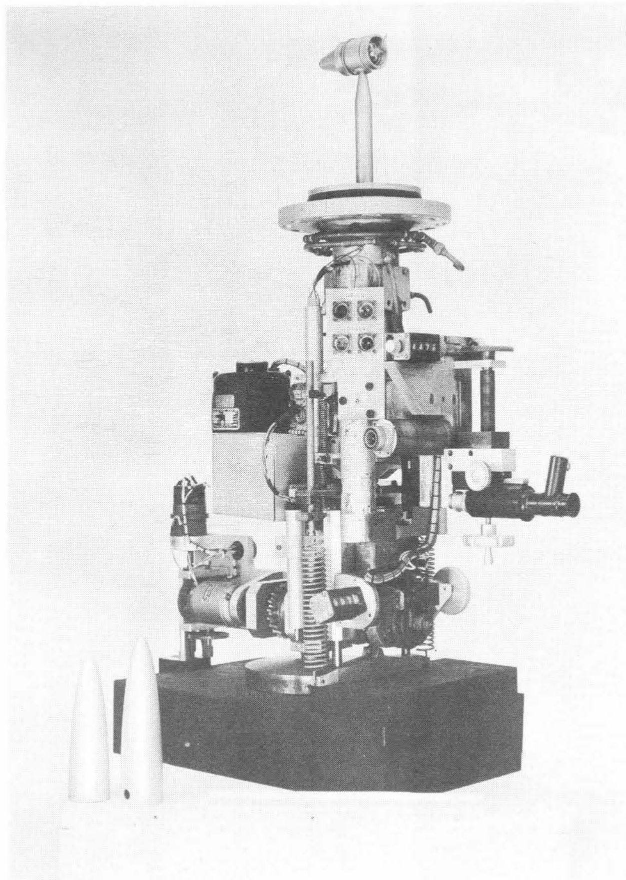

Fig. 2. Translational Dynamic Balance and Ellipsoidal Model

LIST OF PUBLICATIONS

The following publications present the results of work sponsored in whole or in part by this contract:

(1) Knapp, R.T., "Cavitation and Nuclei", Trans. A.S.M.E., Vol. 80, Aug. 1958, pp. 1315-1324.

(2) Kermeen, R.W., "Some Observations of Cavitation on Hemispherical Head Models", California Institute of Technology, Hydrodynamics Laboratory, Report No. E-35.1, June 1952.

(3) Parkin, B.R., "Scale Effects in Cavitating Flow", California Institute of Technology, Hydrodynamics Laboratory, Report No. E-21.8, July 1952.

(4) Parkin, B.R., and Holl, J.W., "Incipient-Cavitation Scaling Experiments for Hemispherical and 1.5-Caliber Ogive-Nosed Bodies", a joint study by the Hydrodynamics Laboratory, California Institute of Technology and the Ordnance Research Laboratory, The Pennsylvania State College, Report No. NOrd 7958-264, May 1953.

(5) Parkin, B.R. and Kermeen, R.W., "Incipient Cavitation and Boundary Layer Interaction on a Streamlined Body", California Institute of Technology, Hydrodynamics Laboratory, Report No. E-35.2, December 1953.

(6) Kermeen, R.W., McGraw, J.T. and Parkin, B.R., "Mechanism of Cavitation Inception and the Related Scale-Effects Problem", Trans. A.S.M.E., Vol. 77, May 1955, pp. 533-541.

(7) Stallkamp, J., "Measurements of Dynamic Coefficients of Ellipsoids", California Institute of Technology, Hydrodynamics Laboratory, Report No. E-35.4, Sept. 1956.

DISTRIBUTION LIST

CONTRACT N6onr-24435, PROJECT NR 062-124

Chief of Naval Research
Department of the Navy
Washington 25, D. C.
Attn: Code 438 (2)

Commanding Officer
Office of Naval Research
Branch Office
The John Crerar Library Bldg.
86 East Randolph Street
Chicago 1, Illinois (1)

Commanding Officer
Office of Naval Research
Branch Office
346 Broadway
New York 13, New York (1)

Commanding Officer
Office of Naval Research
Branch Office
1030 East Green Street
Pasadena 1, California (2)

Commanding Officer
Office of Naval Research
Branch Office
1000 Geary Street
San Francisco 24, California (1)

Commanding Officer
Office of Naval Research
Branch Office
Navy No. 100, Fleet Post Office
New York, New York (2)

Director
Naval Research Laboratory
Washington 25, D. C.
Attn: Code 2021 (6)

Commanding Officer
Naval Ordnance Laboratory
White Oak
Silver Spring, Maryland (1)

Chief, Bureau of Aeronautics
Department of the Navy
Washington 25, D. C.
Attn: Research Division (1)

Chief, Bureau of Ordnance
Department of the Navy
Washington 25, D. C.
Attn: Code Re3d (1)
Code Re6a (1)
Research and Development Div. (1)

Chief, Bureau of Ships
Department of the Navy
Washington 25, D. C.
Attn: Research Division (1)

Commanding Officer and Director
David Taylor Model Basin
Washington 7, D. C.
Attn: Hydrodynamics Division (1)
Technical Library (1)

Commander
Naval Ordnance Test Station
Inyokern, China Lake
California
Attn: Code 5507 (1)

Commander
Naval Ordnance Test Station
3202 East Foothill Blvd.
Pasadena, California
Attn: Code P5507 (1)

Commander
Submarine Development Group TWO
Box 70
U.S. Naval Submarine Base
New London, Connecticut (1)

Office of Ordnance Research
Department of the Army
Washington 25, D. C. (1)

Director of Research
National Advisory Committee
for Aeronautics
1724 F Street, N. W.
Washington 25, D. C. (1)

Director
National Bureau of Standards
National Hydraulics Laboratory
Washington 25, D. C. (1)

DISTRIBUTION LIST

CONTRACT N6onr-24435, PROJECT NR 062-124

(Continued)

Documents Service Center
Armed Service Technical
Information Agency
Knott Building
Dayton 2, Ohio (5)

Mr. C. A. Gongwer
Aerojet General Corporation
332 N. Irwindale Road
Azusa, California (1)

Dr. A. T. Ippen
Hydrodynamics Laboratory
Massachusetts Institute of Technology
Cambridge 39, Mass. (1)

Dr. J. M. Robertson
Ordnance Research Laboratory
Pennsylvania State College
State College, Pennsylvania (1)

Dr. Hunter Rouse, Director
Iowa Institute of Hydraulic Research
State University of Iowa
Iowa City, Iowa (1)

Stevens Institute of Technology
Experimental Towing Tank
711 Hudson Street
Hoboken, New Jersey (1)

Dr. L. G. Straub
St. Anthony Falls Hydraulic
Laboratory
University of Minnesota
Minneapolis 14, Minnesota (1)

Technical Librarian
AVCO Manufacturing Corporation
2385 Revere Beach Parkway
Everett 49, Massachusetts (1)